LCA Case Studies

A Building Sector Related Procedure to Assess the Relevance of the Usage Phase

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Abstract

Intention, Goal, Scope, Background. Life Cycle Assessments (LCA) are increasingly used in the building sector as a decision-support tool in the design phase of buildings to enable environmentally sound choices of materials and products. The practice in Europe of today regarding product choices is mainly based on cradle to gate LCAs and is quite commonly disregarding the usage phase. The main reason for this is the fragmented structure of the building sector in which the application of specific materials and products is unknown to the manufacturer. The environmental information supplied by the manufacturers to the designers of buildings only relates to the production phase, limited to typical cradle to gate data. A specific material or product choice can however have a considerable impact during the usage phase. Predicting the magnitude of an environmental load originating in the usage phase, as the result of a building product can in some cases be based on information on both product- and building level. To date there are no structured procedures for the inclusion of this information in LCA-studies, even-though it is desirable to include the full product life cycle when including environmental parameters in a product choice.

Objective. A procedure for assessing the relevance and the possibility to include the usage phase in a structured way is proposed. Considerable effort has also been put into explaining the underlying obstacles of today's practice in handling the connection between the choice of building products and its resulting impacts in the usage phase.

Methods. The proposed procedure is primary based on experiences and findings from a comprehensive study on maintenance of floor coverings, together with an inventory of the state of the art regarding LCA in the building sector.

Results and Discussion. The procedure is divided into two steps where the first step is a preliminary estimate of the relevance of the usage phase in a building product comparison. Based on this step, step two can be entered. Step two is a judgement of the possibility to quantify the potential environmental loads that can occur in the usage phase. For step one, four different types of sources of potential environmental loads have been found; emissions from the product to the indoor environment, emissions from the product to the outdoor environment, influence on the resource flow in a building, and finally the demands for maintenance, leading to other recurring loads. For step two, the focus in this article is on maintenance, for which a model structure is proposed as a base for the development of a model to estimate the environmental loads. The three other sources of environmental loads are handled more briefly.

Conclusions. The usage phase should to a larger extend be regarded in a product choice situation, when LCA is used as a tool. First, the relevance of including the usage phase should be assessed. Second, the possibility to estimate the environmental loads should be considered. The reason for an exclusion of the usage phase should more clearly be explained, if it is due to lack of relevance or data/models.

Recommendation and Outlook. The proposed procedure shall be regarded as a way to obtain preliminary estimates of the relevance and possibilities to include the usage phase in a product choice situation. Thereby, the handling of the usage phase by the suggested procedure is not a method for estimating the environmental loads but rather a procedure for an inventory of the relevance and possibility to estimate the environmental loads.

Keywords: Building products; decision support; design phase; environment; environmental load; lca; maintenance; product choice; system levels; usage phase

Introduction

The LCA methodology is to a large extent used and developed for environmental assessments of short-lived products, typically found in other industrial sectors than the building sector. LCA is frequently used for assessment of materials and components either for the purpose of comparing different alternative products in a product choice situation or for proposing product improvements. The methodology has to a large extent been adopted by the building sector and has given much valuable input in the work towards sustainable building (SETAC 1999). There are several applications based on LCA in the building sector today. The term building product is used as a term for building materials and components in general.

The characteristics of building products and whole buildings differ considerably from other consumer products. Obvious and distinguishable characteristics of buildings and building products are their significantly longer service life compared to most other industrial products, and the involvement of many different actors during their life cycle. A choice between alternative building products that satisfy the same function for a specific application may, due to the long service life, result in dissimilar loads causing potential environmental impacts in the usage phase. This can in turn have a

significant influence on the total environmental performance, either directly or indirectly (Paulsen 1999a).

When the LCA-methodology is applied in an environmental assessment for a whole building, environmental loads occurring in the usage phase are most often related to the building as a whole and not to the specific choice of a particular building product. Further, when a building product is assessed using the LCA-methodology, e.g. for environmental declaration type III (ISO 2000c), the focus is on the extraction and production processes even-tough the objective of such declarations are to describe the environmental loads associated with the whole life-cycle. The potential environmental impacts that can occur in the usage phase caused by loads are as a consequence often omitted. However, the usage phase might in some cases show to be of major importance from an environmental point of view because of the long service life, which can lead to a sub-optimisation in a product choice situation. Therefore, a closer look at the usage phase is warranted in a product choice situation, and if omitted, this should be more clearly motivated than what is custom today. An omission of the usage phase may only occur if it is found insignificant, or if no satisfactory model exists to estimate the loads, or if important LCI-data is lacking. It is in any case, important to define the reason for the omission.

In the perspective of the above it has to be recognised that there is a need for development of a procedure to bridge the information gap between the building as an integrated system-level and its composing building products to improve the choices of individual building products in an LCA-perspective. Four sources of loads have been found to have a significant influence when potential environmental loads from the usage phase are to be connected to the product choice:

1. Indoor emissions
2. Leach of hazardous substances to the outdoor environment
3. The relative influence on the resource flows in a building
4. The influence of maintenance on environmental loads

Based on the four sources of loads a two-step procedure is presented. Step one aims at providing an preliminary assessment of the relevance of environmental loads, caused by a specific material or product choice. Step two is an evaluation of the possibility to estimate the environmental loads that have been found relevant. Step two is quite brief, although it could, as for maintenance in this article, contain a suggestion of a model structure and an example of a model developed to quantify the potential environmental loads for maintenance of floor coverings.

1 State of the Art in Europe in respect to LCA and the Usage Phase in the Context of Building Products

The implementation of the LCA methodology in the building sector has highlighted several issues that are of utmost importance for a full LCA. Based on the need to adopt the LCA methodology to the unique characteristics of the building sector several working groups have been initiated. One of these is the SETAC Europe working group 'LCA in Building and Construction', which has addressed several of the issues that sets the building sector apart from other sectors, although it

does not consider it unique, when LCA is concerned. The basis is the LCA methodology as defined in ISO 14040-43 (ISO 1997), (ISO 1998a), (ISO 2000a), (ISO 2000b).

In the working group 'SETAC Europe, LCA in Building and Construction' several areas of concern have been determined, which need further research and development to enable implementation of the LCA methodology in the building sector (SETAC 1999). The focus of the working group is on environmental assessment at the whole building level. As a consequence, a sharp distinction has been made between buildings and building products.

According to SETAC Europe, LCA for building products can be performed for two different purposes, either to generate input to whole building assessments or for product comparison/development. In the case of assessment of whole buildings, the LCA is split up into several part-LCAs. The first stage, extraction and production of building products, is based on cradle to gate inventories, independent of the application and usage phase. These LCAs are meant to be a part of a function performed on a higher level, i.e. on the building level. These product or material assessments are not based on 'true' functional units according to the ISO 14040-43, but they are used as input to building LCAs. Those units can be called e.g. 'per tonne' units as used in UK and refer to uninstalled materials. In the Netherlands 'analysis unit' is used, which also can refer to installed material. The consequence of using part-LCAs is that a load that may occur in the usage phase is not taken into account. However, for those part-LCAs it is suggested that at least the probable service life and end-of-life information have to be supplied. The loads that can occur in the usage phase of a whole building are handled separately in a part-LCA that only concerns the usage phase. However, an inventory of several LCA tools (IEA 1999) and case studies (Person 1997), (Björklund 1996) combined with practical experience with the use of several tools (LCAIT, BEAT 2000, ECOLAB) has indicated that LCA-tools for the building sector are in general not developed to handle the usage phase other than by taking into account the number of replacements for building products and by estimating the operational energy consumption. Moreover, the operational energy consumption is calculated on building level, not connected to specific product data, whereas the maintenance and emissions from materials are excluded. Especially the importance of maintenance has been recognised for LCA's in the building sector, but a lack of knowledge of how to deal with it in a proper way has been recognised (SETAC 1999).

For the purpose of product comparison, the whole life cycle of the product has to be taken into account (ISO 1997), (ISO 2000c). Even though both the SETAC working group and ISO 14025 have underlined the importance of including the whole life cycle in a LCI/LCA for product comparison, a tendency towards exclusion of some aspects of the usage phase for building products is pertinent to the industry.

The ISO-standard for environmental declaration Type III, ISO 14025 (ISO 2000c), states that relevant parts of the whole life cycle of a product should be included based on

the needs of the end user. The ISO-standard defines two types of end users: consumer and industrial/commercial end users. Type III declarations that are addressed to consumers shall include the whole life cycle from cradle to grave. Declarations addressed to the industrial/commercial end-users, in the context of the building sector for instance designers or architects, do however not have to be considered from cradle to grave. The supplier of the product is allowed to only include those stages that are found relevant, e.g. cradle to gate information, assuming the industrial/commercial end-users have knowledge of the impacts in the usage phase. Precautions should therefore be taken to minimise the risk of exclusion of the usage phase for building products, which can occur due to lack of information transfer between the product supplier and the industrial/ commercial end-users

An inventory of type III declarations in Sweden (Erlandsson 1996), (Erlandsson and Andersson 1997), Finland (Vares 2000), (Häkkinen and Vesikari 1997) and Norway (NBI 1999) has been carried out, all showing that the declarations are primarily based on cradle to gate assessments. Some attempts are done to estimate the standard service life according to the ISO/DIS 15686-1 (ISO 1998b), and supply a classification of the emissions to the indoor environment. However, a survey of current type III declarations reveals that the usage phase generally is omitted in those declarations. This causes risk to be neglected unless the commercial/industrial end-user takes it into account.

2 Building Specific Considerations

The problems with information transfer of LCA-data between production stages and downstream use of building products can be attributed to some characteristics that are specific for the building sector.

The LCA methodology can be used in the building sector as a decision support instrument for a choice between alternative building products. When the LCA methodology is used for comparative studies, two issues are important to remember:

1) LCA regards the whole life cycle, from cradle to grave
2) It is the function/service, which creates the basis for comparison and not the product itself

In **Fig. 1**, a schematic illustration is given over the life cycle of an arbitrary building product. The life cycle is divided into 6 stages, and each stage is characterised dealing with the building on one or more of four different system levels (Paulsen 1999a). The life cycle stages are related to chronological life stages of the product. It should be noticed that the figure is schematic and that the length of the life cycle stages is not in proportion to each other. The usage phase is the dominant period of time. A step up in system level is accompanied by an increase in the complexity of the structure in which the assembled product participates. The actors that influence the impacts from the product (related to the functional unit) vary during the life cycle.

Individual building products do in general not provide a function on system levels 1, 2 and 3 (Fig. 1), but applied in a building, i.e. system level 4, the product can be considered to provide a function and thus be ascribed a functional unit. The building level provides the necessary time perspective and context for the product to define its proper functional unit. The product context and predicted service life is essential to monitor the impacts from the usage phase. This means that it actually is impossible to carry out an LCA for a product, taking the whole life cycle into account, unless its aggregated application is known, i.e. information on every system level is available. Furthermore, knowledge is needed concerning all the environmental loads related to the usage phase of the function during its service life, the expected service life and the environmental loads from the waste treatment phase.
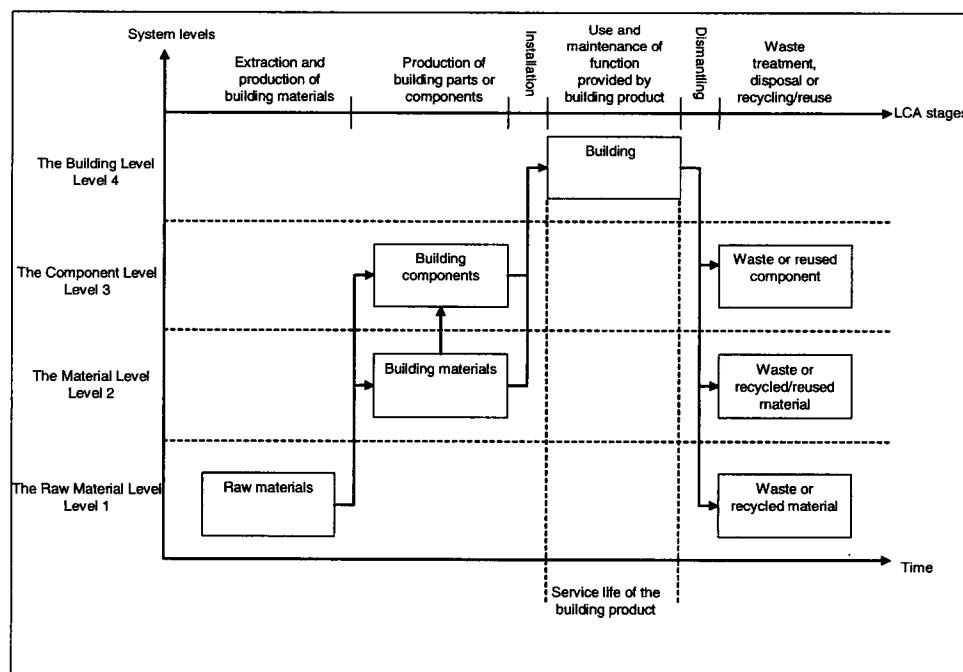

Fig. 1: System levels in a building products life cycle

The producer of a building product can be expected to have good knowledge of the first steps in the product lifecycle, i.e. related to raw material extraction and production process. He is thereby able to perform an accurate cradle to gate assessment. However, a variety of applications can exist for a product performing different functions in the usage phase. Even though the application possibilities can be limited to a reasonable number, the magnitude of environmental loads from the usage phase can vary broadly caused by building related and external parameters. For example, the maintenance of a facade can be strongly dependent on the local climate as well as aesthetic demands.

From this perspective, the system levels can be divided into two superior system levels.

1. The product level, before and after the use of the product in a building. The product does not provide a useful function in these phases
2. The building level, at which a product provides a function, often supported by other (aggregated or assembled) products and services (e.g. maintenance)

Further, the building product life cycle can be divided into three main phases:

1. Prior to installation in a building (The product production phase)
2. During use in a building (The product usage phase)
3. After the product is removed from the building (The product waste treatment phase)

Several environmental loads occur during the usage phase of a building. Some loads are related to services, which cannot be connected to the choice of specific building products and some loads are influenced by the choice of a specific product.

An attempt has been made to classify the sources of environmental loads, which can influence the environmental flows in the usage phase, either directly or indirectly connected to a specific building product choice. This classification is important for determining when it is relevant to include the usage phase. Four classes of sources of potential environmental loads have been identified:

1. Emission to the indoor environment from products
2. Emission to the outdoor environment from products, e.g. leaching of hazardous substances
3. Interference with the resource flows in building systems, e.g. energy use or water use
4. Consumption of auxiliary products and resources for maintenance, e.g. cleaning or painting

3 A Procedure for Dealing with the Usage Phase in Environmental Assessment of Building Products

The proposed procedure is based on two distinctive steps:

1. Identify whether it is relevant to include the usage phase in a comparative assertion in the context of a building product choice. The relevant criteria is that the building product has to have a significant or significantly different environmental load in the usage phase compared to other alternatives based on the current application
2. When it has been established that the usage phase is relevant and the types of loads are recognised, the viability to estimate their magnitudes has to be examined

Step one of the procedure combines information at the product level with information at the building level to verify whether it is relevant to include the usage phase regarding four identified sources of environmental loads. Actually, no exact answer can be given about the relevance of including the usage phase in this stage. The magnitude of loads and thereby their significance can only be determined after a full inventory of the usage phase. However, the problem with deciding what to include in a LCA is recognised in the ISO 14041 goal and scope definition (ISO 1998a) which states that: "*Any decision to omit life cycle stages, processes or input/output shall be clearly stated and justified*". The first step of this procedure can then be seen as part of the justification of the inclusion or exclusion of the usage phase. If the outcome of step one is that the product choice will probably influence the environmental loads significantly, the actor can proceed to step two and assess the possibility to estimate the loads for the sources that have been identified (**Figs. 2 and 3**).
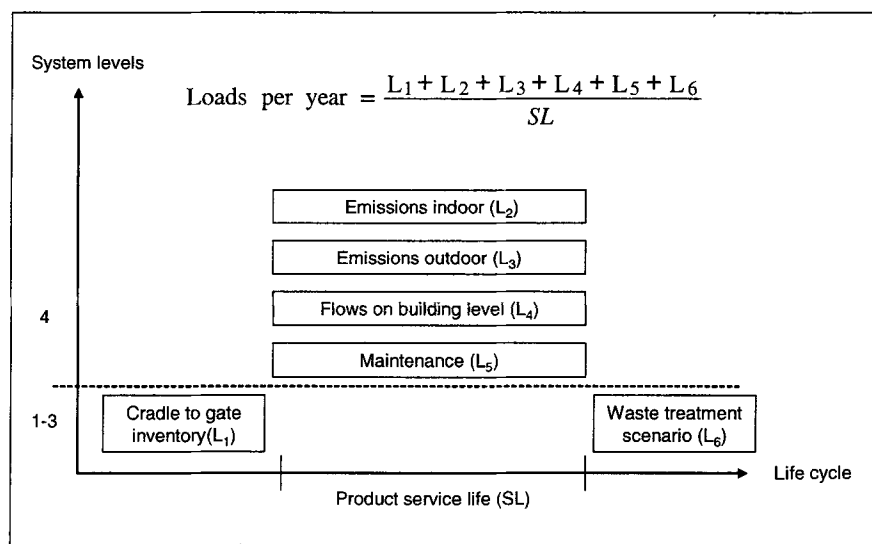

System levels

$$\text{Loads per year} = \frac{L_1 + L_2 + L_3 + L_4 + L_5 + L_6}{SL}$$

4 — Emissions indoor (L_2) / Emissions outdoor (L_3) / Flows on building level (L_4) / Maintenance (L_5)

1-3 — Cradle to gate inventory(L_1) / Waste treatment scenario (L_6)

Product service life (SL)   Life cycle

Fig. 2: Relevant environmental loads caused by a specific product choice, taking the whole life cycle into account
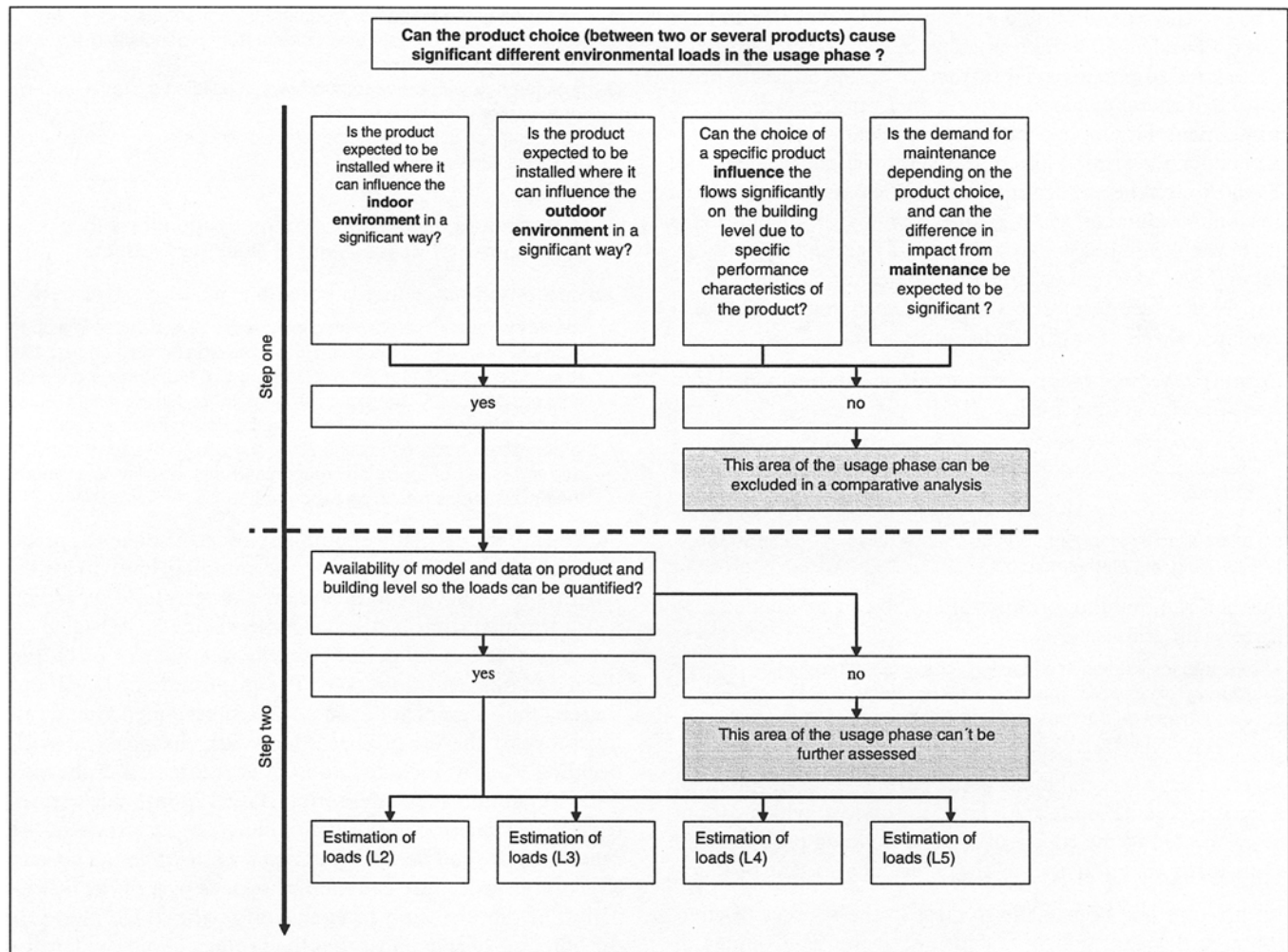
Fig. 3: Procedure to estimate environmental loads originating in the usage phase

Step two is where the possibility to estimate the potential environmental loads in the usage phase has to be assessed depending on whether a model exists and whether there is accurate input data to the model. The input data are divided into three groups:

1. Building specific data
2. Product data for the analysed product
3. LCI-data for influenced resource flows

The 'LCI-data for influenced resource flows' only deal with the maintenance and resource flows. If it is found not possible to estimate the loads in the usage phase in a satisfactory way because of lack of model or data, the exact reason should be given in the motivation and justification for omitting the usage phase. This would provide better information for the interpretation (ISO 2000b), although it is obviously better to use reliable estimates instead.

In Fig. 2, the six boxes illustrate the sources of environmental loads from the whole life cycle caused by a product choice. The four boxes above the dotted line refer to the four identified sources of loads (L2 to L5) that can contribute to the impacts in the usage phase caused by a product choice (Fig. 3). The environmental loads for each box are symbolised L_i.

The dotted line symbolises the border between the product level (i=1 to 3) and building level (i=4), see Fig. 1. The loads from the production process (L_1), also called the cradle to gate inventory together with the loads from waste treatment (L_6) can normally be estimated on the product level, regardless of the application in a building.

The summation of the loads L_1 to L_6 will result in the total environmental loads caused by a specific product choice through the service life of the product. However, if a product comparison has to be done, it is important that the comparison is done on the same basis. Since two products for the same application can have different service lives, this has to be taken into account. Therefore, the Service Life (SL) has to be estimated for each of the products that shall be compared. Then, the products can be compared on the basis 'loads per year' after dividing the total loads with the service life. If desirable, the loads can further be treated in an impact assessment according to ISO 14042 (ISO 2000a). To predict the service life, information on the building level should be used to detect the type of service life, e.g. economic, technical, aesthetic or any other aspect, that is critical to the service life for the current study.

3.1 Possibilities to estimate the environmental loads from the usage phase

Four different sources of environmental loads in the usage phase (caused by a specific product choice) have been identified. Methods for estimating the magnitude of the environmental loads are still under development and will briefly be discussed in the following. However, for the topic 'maintenance' a model structure will be proposed, The model structure can be used as a base for development of a model for estimating the environmental loads in the usage phase. The model structure-proposal regarding maintenance is based on findings and experience from a larger case study on floor coverings in Sweden (Paulsen 1999b).

Emissions to the indoor environment (L_2). It is realised that the indoor environment is an important performance parameter of buildings. Sick Building Syndrome (SBS) is a direct consequence of indoor emissions. The relevance of including indoor environment in a specific material choice depends to a large extent on the intended application in the building. In for example a Kindergarten, the indoor environment will have a high priority, whereas its relevance is low in a storage hall. If the indoor emissions are expected to be important, the possibility to estimate the loads depends on several conditions. A model is needed to describe the transport mechanisms that cause the emissions, the substances in the product that transforms into emissions and the building specific conditions that influence the emissions in relation to actual transport mechanisms.

In Denmark, a method for labelling of building products based on their impact on the indoor climate has been developed. In the method emissions are measured under standard conditions to estimate a time value. The time value is the period of time that elapses until the unwanted emissions reach an acceptable level (SBI 2000). It should be possible to quantify the amount of emissions and use those as LCI data. Emissions data from several products can then be added in e.g. a larger comparison of material combinations, using the LCI-emission data. An advantage of measuring the emissions to the indoor environment is that the standard conditions for the laboratory test are very close to the normal conditions in an actual building. Assuming the test conditions are valid for the actual product application it would be acceptable to use the emission data without any theoretical model or data on product or building level.

However, the actual effects on human from emissions affecting human health are difficult to assess in an LCA, see e.g. (Jönsson 1999). One suggestion is to compare products based on potential emissions and not try to estimate the effect on human health

Emissions to the outdoor environment (L_3). Some types of building products can be expected to leach substances that can affect the external environment (Andersson 1999), (Persson and Kucera 1998), (Johansson et al 1999). Also, the debate on PCB is a result of product emission. The relevance of including emissions to the outdoor environment in a product choice depends on the potential effects on the surroundings. Using materials, which contain significant hazardous substances or large amounts of materials with some hazardous contents could mandate to include the emissions to the outdoor environment in a comparative product assessment.

As for emissions to the indoor environment, in order to quantify the loads for outdoor emissions the same type of information is needed; i.e. a model and data on product and building level. Similar to the indoor emissions, tests have been carried out to estimate the emissions (Andersson 1999), (Persson and Kucera 1998), (Johansson et al. 1999). However, an obstacle is that the test conditions can only cover single cases and situations, which can be hard to translate to an actual application under different conditions. This is an area that needs further research. In most cases, this part of the usage phase will be omitted because of lack of adequate models and data.

Influence on resource flows on the building level (L_4). In some cases the choice of building products can indirectly affect the environmental loads of the whole building by influencing the resource flows through the building. Water and energy are two types of resource flows that can be influenced by specific product choices. Water is not regarded as a particular polluting or scarce resource in Scandinavia and will not be further discussed.

Several case studies have shown that energy use during the usage phase for a building is very large compared to the embodied energy in the building products. (Björklund et al. 1996), (Adalberth 2000). If a choice between two (or more) building products will result in significantly different energy use for the whole building, it is important to include in a comparative product LCA. The differences in environmental burdens for production of the building product can thereby be set in relation to the marginal difference in impacts in the usage phase; an example is given in (Jóhannesson and Levin 1998). The example in (Jóhannesson and Levin 1998) actually shows that the impacts from the difference in energy use for the application of two different materials were significantly larger than the difference in impact from the production of the products. A product choice solely based on the cradle to gate inventory would have led to a sub-optimisation of the whole building. The relevance of including the impact on energy use of a material choice, seems most relevant for those materials in the building, that influence the thermal storage or the heat loses trough the building envelope significantly. The possibility to estimate the difference in energy use for different material choices depends on available data and methods. This requires an energy simulation model for the whole building, connected with material data and other inputs such as position of building, indoor temperature etc. Data on product level relates to heat resistance, thermal storage capacity and density. The outcome of such a simulation is a difference in energy use for a given period (related to service life of products). This 'marginal' difference in energy use cannot be assigned to a single product on the product level. The marginal difference in energy use is only valid for the product in the given context. If several product combinations are compared, the marginal energy use is valid for the product combination in the given context (and is not possible so 'share' between products in the product combination).

The marginal difference in energy use can be used as an impact indicator and be compared with the difference in the LCI-profiles for the studied products. The energy use can also be transformed into a LCI profile, but thereby further assumptions are needed regarding energy supply systems and how these will change over time.

Environmental loads from maintenance (L_5). Many building products require some kind of maintenance, e.g. cleaning and painting, during their service life to maintain the desired function or service. The environmental loads from maintenance can be significant due to the long service life of building products (Paulsen 1999b). The relevance of including the maintenance depends on the magnitude of the resource use. Thereby, the frequency of maintenance and the potential hazardousness of these resources can be used as indicators of the relevance of including maintenance in a product choice situation. Furthermore, there has to be a significant difference in the demand for maintenance between two or more product alternatives before it is relevant to include maintenance aspects. In this context, it can be discussed that poor or 'no maintenance' also are alternatives that will actually reduce this load (L5). However, the result will probably be a total increase in 'load per year' (see Fig. 2) caused by a shorter lifetime. The equation in Fig. 2 shows that the total load per year is more sensitive to a reduction in service life than a reduction of the loads from maintenance.

To be able to estimate the potential environmental loads from maintenance, a model is needed to estimate the resource use for maintenance as a function of product choice (the product which needs maintenance) and building context. Environmental loads caused by maintenance in the usage phase can be related to the resource use for maintenance products and machinery to carry out the maintenance. The amounts of resources used are depending on the types of maintenance e.g. type of auxiliary products and machinery that can be estimated on the product level. Further, information is needed on the building level regarding intervals for maintenance. In the following a procedure is proposed to estimate environmental loads from maintenance.

3.2 A proposal of a structure for development of a model to estimate environmental loads from maintenance

This proposal is based on a larger case study on floor coverings in Sweden (Paulsen 1999a,b). A comparison of linoleum and PVC-flooring was carried out for the public and service sector.

In LCA of floor coverings, the maintenance was found relevant because of high frequency of maintenance, the use of chemicals, and because linoleum and PVC are maintained in different ways. The estimation of the loads from the usage phase was found possible when 5 conditions were met:

1. One can make a generalisation and limitation of relevant maintenance methods
2. One can make a generalisation and limitation of relevant auxiliary products and machinery for maintenance
3. One can assume that the intervals of maintenance are constant over time with the selected maintenance method
4. Factors like service life and frequency for maintenance can be estimated in the planning and construction stage depending on building product chosen
5. One can create LCI-profiles for the auxiliary products and machines

For condition 1–4 there was found general agreement in the Swedish commercial floor-cleaning sector. This was a prerequisite for making a model for the estimation of loads. For condition 5 some data had to be estimated, however, the data quality was found high enough to satisfy the goal of the study. It is argued that the 5 listed conditions can be used in general for maintenance of building products.

Table 1: Definition of intervals for different types of maintenance

Type of maintenance	Symbol	Frequency
Frequently maintenance	F	Several times at month
Periodical maintenance	P	0.2-2 times per year
Upgrading maintenance	U	Some time under the service life

In the case study the estimation of loads was complicated by the fact that there was an interaction between several types of maintenance. Three different types of maintenance were found (Table 1).

These definitions are taken from the Swedish sector for maintenance of floor coverings but can probably be used as an expression for maintenance of building products in general. The relevant maintenance types depend on the actual product and its application. The reason for the division into the three groups of maintenance is to guarantee that all the aspects of maintenance are covered. A decrease in frequently maintenance can for example result in an increase for the periodical maintenance, which is the case for floor coverings.

The frequent maintenance will normally regard environmental loads from e.g. cleaning, which results in a relative low impact, but it occurs repeatedly. Periodical maintenance can vary between several times a year and several years between maintenance activities. This results in a much larger environmental load per occasion compared to frequent maintenance, but with a much longer period between the occasions. The upgrading maintenance is a parameter for those products that needs occasional intensive treatment to reach the predicted service life. This is only relevant if the demanded type of upgrading maintenance differs significantly from the periodical maintenance.

Besides the division into the three types of maintenance in the case study, a further division was done between the environmental loads for auxiliary products and the environmental loads for machinery. In Table 2, the resulting six parameters are shown with their index symbols.

Table 2: Load parameters with their index symbols

Source to environmental load	Maintenance stages		
	Frequent	Periodical	Upgrading
Environmental load from products	L_{pf}	L_{pp}	L_{pu}
Environmental load from machinery	L_{mf}	L_{mp}	L_{mu}
Total per stage	L_f	L_p	L_u

Then, for each of the three maintenance stages, the number of considered types of maintenance methods and auxiliary materials and products was limited according to conditions 1 and 2. For each method the use of auxiliary products and machinery was quantified per maintenance occasion (called A_x). The corresponding LCI-profile was created for each product and use of machinery (L_x) according to condition 5. Further, assuming that the maintenance demand did not increase over time with the selected maintenance method (according to condition 3), a calculation was done to estimate the environmental load occurring in the usage phase, see equation 1–4:

$$Lf = SL * \left[F * \left(\sum_{n=1}^{n=k_1} A_{fmn} * L_{fmn} + \sum_{n=1}^{n=k_2} A_{fpn} * L_{fpn} \right) \right] \quad (1)$$

$$Lp = SL * \left[P * \left(\sum_{n=1}^{n=k_3} A_{pmn} * L_{pmn} + \sum_{n=1}^{n=k_4} A_{ppn} * L_{ppn} \right) \right] \quad (2)$$

$$Lu = SL * \left[U * \left(\sum_{n=1}^{n=k_5} A_{umn} * L_{umn} + \sum_{n=1}^{n=k_6} A_{upn} * L_{upn} \right) \right] \quad (3)$$

$$Ltot = Lf + Lp + Lu \quad (4)$$

where (in Equation 1):

A_{fmn} is the Amount (A) of resources for one occasion of frequent (f) maintenance with machine (m) number n (n).

L_{fmn} is the LCI-profile of the machine (m) number (n) for the frequent (f) maintenance.

k_1 are the number of machines for frequent maintenance

A_{fpn} is the Amount (A) of products (p) for one occasion of frequent maintenance (f) for product number n (n).

L_{fpn} is the LCI profile for the product (p) number (n) for the frequent (f) maintenance.

k_2 are the number of products for frequent maintenance

F is the frequency of the Frequent maintenance (times per year)

SL is the length of the Service Life (year)

In Equations 2 and 3, the environmental load from periodical and upgrading maintenance events are calculated in a similar way where:

P is the frequency of the Periodical maintenance

U is the frequency of the Upgrading maintenance

k_3, k_5 are the number of machines used for periodical and upgrading maintenance respectively.

k_4, k_6 are the number of products used for periodical and upgrading maintenance respectively.

Equations 1–3 give the environmental load from the frequent, periodical and upgrading maintenance respectively. Equation 4 is a summary of equation 1 to 3, and thereby the total environmental load from the usage phase caused by maintenance over the service life.

A calculation program was developed to handle different scenarios. For maintenance, 13 methods were found relevant in the Swedish sector for professional cleaning. The frequencies of the maintenance (F, P and U) were found to be depending on the building type, not the floor covering or maintenance method. Also it was found more significant to decide the actual service life for a floor covering when it was related to the building type than to the type of floor covering. Therefore, the computer program, contains all data about methods, cleaning products, machinery, floor coverings, etc. To compare the usage phase (together with the cradle to gate inventory of the floor coverings) input data has to be selected on building level, like the appropriate maintenance methods (out of 13 variants), the expected frequencies for maintenance (F, P and U) together with the expected service life. For some building types the service life was found to be depending on the change of tenants, which means that the service life will be the same for the two types of floor coverings, and significantly shorter than the technical service life. For other building types the service life was found to be depending of the technical service life.

Example. In this example the results is shown for the comparison of four different maintenance scenarios. The studied object is a resilient floor covering in an office, which requires cleaning 3 times a week and a periodical maintenance ones a year. Upgrading maintenance is not relevant in this case. The estimated service life is 7 years based on the type of building. Thereby, the parameters F, P, U and SL are known (F=156 times/year, P=1 time/year, U=0, SL= 7 years). Two different maintenance systems and two different floor coverings can be chosen (Table 3).

Table 3: Four scenarios for maintenance of floor coverings

	Combi-machine	Moister mopping
Linoleum flooring	Polish and all purpose cleaner	Wax and wax-based cleaner
PVC flooring	Polish and all purpose cleaner	Wax and wax-based cleaner

It can be noticed that methods with combi-machines are more resource consuming than moister mopping. Further, it can be noticed that periodical maintenance with polish is more resource consuming than wax-based systems but for the frequent maintenance (cleaning) the situation is the opposite. The LCI profiles for the products (L_{fpn}) and machinery (L_{fmn}) contain several parameters, but here only two environmental indicators will be shown to illustrate the principles. In Table 4 the result is shown as the magnitude of environmental indicators per m^2 during the service life:

Table 4: Magnitude of environmental indicators per m^2 under the service life for floor coverings

	Combi-machine	Combi-machine	Moister mopping	Moister mopping
	Litre of chemicals	MJ	Litre of chemicals	MJ
Linoleum flooring	1.78	69.0	0.31	37.0
PVC flooring	1.11	49.2	0.20	34.1

As a reference it can be mentioned that the difference in total energy use for the production of linoleum and PVC are approximately 8 MJ/m^2. The results show that the choice of material and method has a significant influence on the total environmental loads during the life cycle of the floor coverings.

It is suggested here that the same structure can be used for other building products as a general approach. The first step will be to detect which parameters that are of relevant. By using the suggested structure as a base in the assessment, it is easier to compare differences in the environmental loads, because each part of the maintenance aspects can be compared. The suggested structure can support the development of inventory-tools for the maintenance for relevant product groups. Further research is needed to collect relevant LCI-data and create flexible models and calculation programs for the usage phase.

4 Results and Discussion

The goal of the presented proposal is to broaden the base for decision support when environmental issues constitute one of the decision parameters that have to be considered. The reason for this is that decision support of building product choices does at present not include the loads that appear during the long service life of buildings. These loads can have a signifi-

cant influence on the choice of product. The presented procedure is meant to make it easier to take the usage phase into consideration in building product choice situations.

One obvious obstacle to carry out an inventory of the usage phase in a product choice situation is the time perspective. In the design phase of a building, there is seldom time to start an LCI-data collection procedure and carry out a comprehensive study. As in the case with the floor coverings, it took almost two years to collect data and create the model. However, once the calculation program and the data exists, only six values are needed as input on building level: frequency of maintenance (F, P and U), an estimate of the relevant service life of the floor covering (SL), a choice of maintenance method (13 different variants) and finally, the type of floor covering (two alternative types). With the aid of the model an estimation of the environmental loads from floor coverings, taking the usage phase into account, only takes a minute.

The computer program used in the study of floor coverings has not been further developed to a more commercial and user-friendly product but the framework exists and it is very easy to add new data. After the publishing in 1999 several additional scenarios have been carried out for some of the larger actors in the Swedish floor covering industry. By adding a small amount of data it has been possible to draw some important conclusions from different scenarios regarding the loads from the usage phase.

Another obstacle to take the usage phase into account is the long time perspective, which causes a considerable increase in uncertainty for the modelled scenarios. For the emissions from building products to the indoor and external environment, the time perspective will not affect the uncertainty as much as for the maintenance and its influence on energy use in the usage phase. For maintenance, the development of new auxiliary products and machinery can change expected environmental loads considerably in the future. Also, the environmental loads per produced MJ can change considerably regarding the change in future energy production. These factors are difficult to predict, but they can be taken into consideration in a calculation model using an acceptable scenario regarding the future developments.

5   Conclusions

The usage phase should to a larger extend be regarded in a product choice situation, when LCA is used as a tool. First, the relevance of including the usage phase should be assessed. Second, the possibility to estimate the environmental loads should be considered. The reason for an exclusion of the usage phase should more clearly be explained, if it is due to lack of relevance or data/models.

6   Recommendations and Outlook

A reflection on the relevance and benefits of taking the usage phase into account for product choices should deal with the methodological issues. The development of the LCA methodology over the last ten years and its implementation in many different applications in the building sector has probably not always led to correct decisions from an environmental viewpoint. However, it has significantly increased the awareness and knowledge of environmental consequences and impacts

from many products and processes. Dealing with the usage phase for building products will hopefully increase the knowledge of some new and important environmental aspects.

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